NASA-CR-65092

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FIRST QUARTERLY REPORT

DESIGN STUDY
FOR
LUNAR EXPLORATION HAND TOOLS

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January 1965

Prepared under Contract No. NAS 9-3647 by

MARTIN COMPANY
Baltimore, Maryland 21203

Martin Report No. ER 13766

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MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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ABSTRACT

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The purpose of this report is to present the results of the first three months work performed for the Design Study of Lunar Exploration Hand Tools, under NASA contract NAS 9-3647. A review of current authoritative interpretations of lunar surface geology and environment was conducted and the need for a portable, battery-powered specimen sampling tool was established. Preliminary lunar gravity simulator tests were performed to define the optimum size for the power tool. Basic design criteria were established, a battery power pack was selected, motor and mechanism approaches were determined, and an integrated configuration envelope was defined.

Author

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SUMMARY

The preliminary basic data evaluation has revealed that the spacesuited lunar astronaut may require a variety of tool capabilities in order to procure a representative sampling of the expected lunar surface materials. The procurement of geological specimens from "welded" dust, rock outcrops, or blocks of rubble can best be accomplished by a power tool incorporating a chipping and coring capability. Unconsolidated dust and crushed rock can best be obtained with a long-handled scoop or shovel. Procurement of larger, unb roken samples of fragmental clastic matter with unusual structures (fairycastle, tinker toy, etc.) may require the use of a spade-like tool.

Preliminary lunar gravity simulator tests were conducted in order to define an optimum design envelope for the Powered Lunar Geologist Tool (PLGT). The length of the tool and spacing between control handles were varied to ascertain the optimum configuration for the application of maximum torque and pressure by the spacesuited astronaut. It was determined that an overall tool length of 41 inches,with 5-inch handles,was required to assure maximum astronaut controllability.

Design criteria were established for the PLGT and a design envelope for the tool was defined. The following functions and capabilities are planned for the PLGT:

1. Capable of coring or chipping geological specimens from the lunar surface by use of a battery powered percussor.

2. Contains integrated sample containers to provide temporary stowage for the geological specimens.

3. Incorporates a telescoping "Jacob's staff" which serves as a stadia rod and solar compass (or camera) support.

INTRODUCTION

The techniques for collecting terrrestrial surface materials for geological analysis have not changed significantly during the past several hundred years. The 1965 geologist still utilizes a pick, shovel, hand-operated coring device, collection receptacles, and muscle power as basic tools of his profession. However, these relatively simple tools and techniques muat be significantly modified in order to be successfully utilized on the lunar surface with its accompanying safety hazards, environmental extremes, reduced gravity and human dexterity limitations.

The mission objectives of a lunar geological exploration excursion are similar to those of a terrestrial mission involving a previously unexplored area. Basically, the geologist is interested in obtaining lunar surface specimens which can be analyzed in order to determine the composition and relative quantities of materials with respect to their selenographic coordinates. Therefore, this Study involves the translation of a terrestrial geological mission into one which is suitable for the lunar surface, with emphasis on the new equipment and techniques required for the strange environment.

The initial phase of this Study consists of an evaluation of the basic data influencing the design of the geological exploration hand tools. This includes the lunar geological and environmental factors, human factors, and Apollo-LEM characteristics. As a result of the basic data evaluation, a potential design approach is selected for the PLGT and related auxiliary equipment. Preliminary operating parameters have been established and detailed design studies are currently in progress.

This report includes the work performed from October 26, 1964 through January 26, 1965 and was conducted under the auspices of Mr. M. B. Goldman, Manager of Logistic Support and Mr. J. F. Christopher, Advanced Logistics Staff supervisor, Baltimore Division, Martin Company. Other individuals and their specialty areas, who are contributing to this program include:

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BASIC DATA EVALUATION

An evaluation of pertinent background information is required prior to establishing preliminary design criteria for the Powered Lunar Geologist Tool (PLGT) and auxiliary geological equipment. The evaluation and interpretation of this preliminary data establishes the initial guidelines for the Study. As additional information becomes available, further refinements in the approach for tool selection can be incorporated.

The primary areas which require study include the astronaut safety and human factors considerations, lunar environmental and geological factors, and the Apollo-LEM interfaces.

Safety and Human Factors

The purpose of this preliminary study is to consider the basic human factors elements necessary in transporting and operating the tool on the lunar surface in addition to developing a working envelope for the operator wearing a pressure suit.

The PLGT is essentially a miniaturized version of an impact tool used for breaking concrete and other substances for construction and repair. However, the lunar tool must be lightweight, and transmission of reaction forces to the astronaut must be minimized. The latter can be accomplished by self-cancelling techniques, or by transfer of reactive torque mechanically to the lunar surface during the core drilling process.

A number of potentially dangerous hazards to the astronaut may appear on the lunar surface, or through the use of an improperly designed tool. These include: 1) stumbling over surface protrusions, resulting in spacesuit puncture; 2) dropping tools on the surface, resulting in excessive work for retrieval; and 3) misdirected or deflected blow from use of a standard geologist's pick, chisel or hammer, resulting in spacesuit puncture. These are but a few of the safety factors which must be considered in the tool design for efficient and successful operation. Thus, the PLGT should not require an operator in a pressure suit, who is already limited or restricted in his mobility, to work in a stooping or squatting position. In addition, the auxiliary geological tools required for the lunar mission (clinometer, compass, sample carrying case, etc.) should be integrated into the design of the PLGT where possible in order to reduce excessive handling and droppage problems.

The basic tasks required of the human operator while obtaining a specimen are as follows:

- Transport tool and navigate to anticipated work area.
- Locate, identify and select samples to be obtained.
- Prepare PLGT for specimen collection.
- Obtain specimen.
- Store specimen (temporarily) for return to the LEM spacecraft.

The astronaut will be required to apply pushing and rotational (torque) forces simultaneously while operating the tool in the coring mode. The rotational force will be required to counteract the torque of the tool, and the vertical pushing force is required to maintain sufficient cutting pressure between the cutter and lunar surface rock. The force requirements must be within the human operator's capability while operating within a pressure suit in the lunar environment.

In order to evaluate the force capabilities of an astronaut on the lunar surface, a study was conducted employing the Martin Lunar Gravity Simulator, and a simple mockup of the PLGT. Figures 1, 2, and 3 illustrate the equipment which was utilized during these tests. The operator was suspended in the 5-Degree-of-Freedom Simulator. This air-pad bearing device allows frictionless translation of the operator in any direction in the horizontal plane, plus rotational freedom in the pitch, yaw and roll axes. The floor of the simulator, which represents the "lunar surface", is counterbalanced in such a manner as to allow the "surface" to press upward against the operator's feet with a force equal to one-sixth of his body weight.

The specific purpose of the study was to establish heights above the surface, and distances in front of the operator, where maximum forces and torques could be applied to the PLGT. Although the Apollo spacesuit was not available for the tests, the results of the force measurements represent a reasonably accurate interpolation of the spacesuited operator's capability.

The PLGT mockup consisted of two telescoping segments of aluminum tubing with a T-bar located at one end, and a wrench socket secured inside the opposite end of the tubing. Holes for locking pins were spaced along the entire length of the tubing at one-inch intervals. Thus, the length of the tool could be adjusted. A second adjustable handle for lifting and controlling the tool in the horizontal plane was located below the T-bar.

Three subjects were tested individually, each wearing field boots with rubber soles and heels. These boots were very similar to the prototype Apollo boots, and possessed a coefficient of static friction of 0.5 with the plywood surface. The subjects were individually placed in the simulator and "balanced out" so that 1/6th of their total weight was exerted upward on the bottom of the feet. A scale was placed on the simulator platform, and downward force measurements were recorded as the subjects applied force on the scale with the tool. For torquing, a 9/16-inch bolt was secured through the simulator platform. The subjects placed the socket over the bolt and applied maximum torque in a clockwise direction. The experimenter then torqued the bolt with a torque wrench and noted the maximum torque applied prior to further tightening of the bolt.

Force and torque measurements were made at T-bar heights of 35, 40, 45, 50, 55, and 60 inches, as well as tool-to-toe distances of 0, 3, 6, 9, 12, and 15 inches. Measurements were initially recorded with the feet unrestrained. Secondly, to gain an idea of what the operator might do with the feet restrained, four wooden slats were attached to the bottom of the simulator platform. The subject then placed his feet between the slats and torque measurements (only)

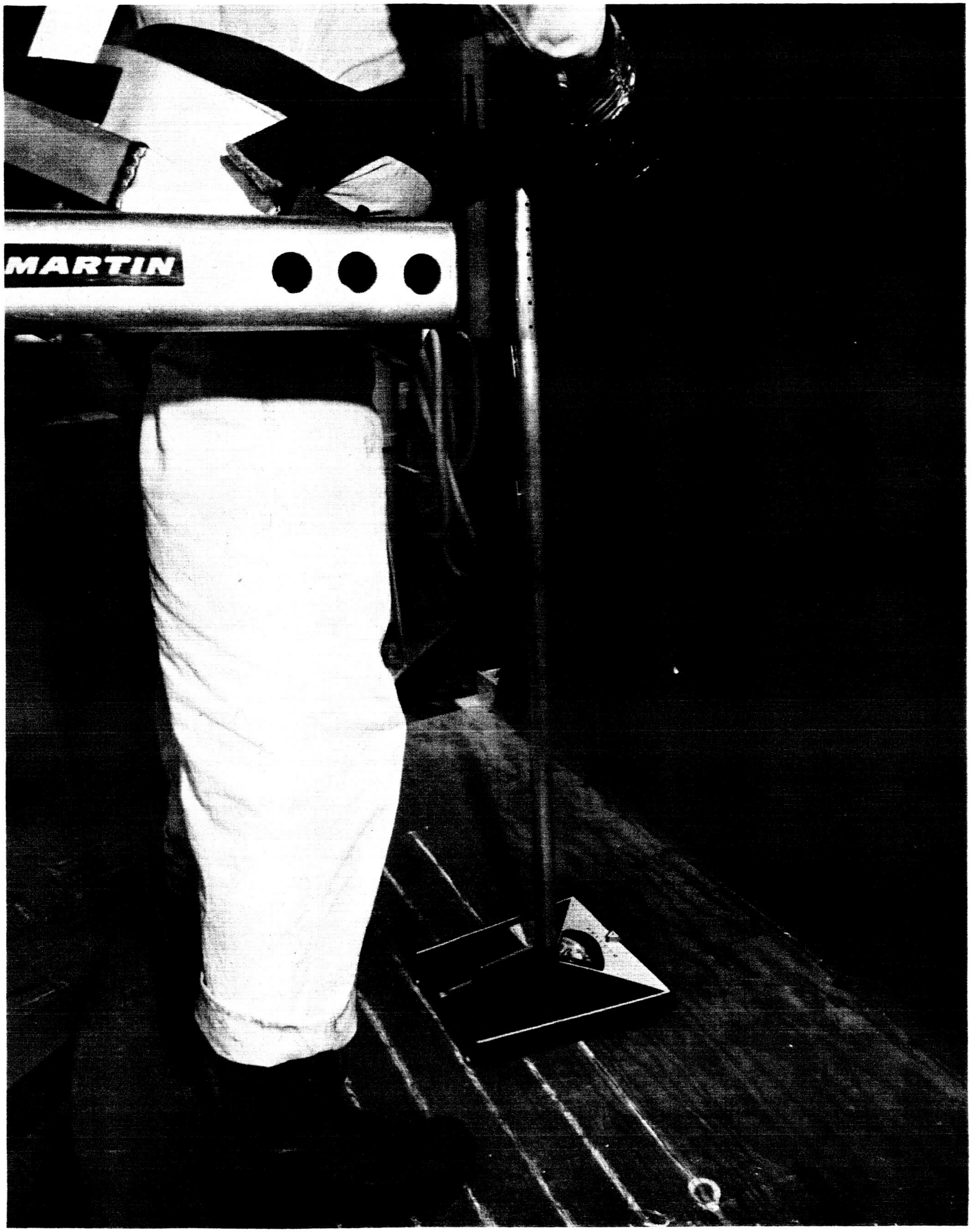

Figure 1. Determination of Maximum Axial PLGT Pressure Under 1/6-G

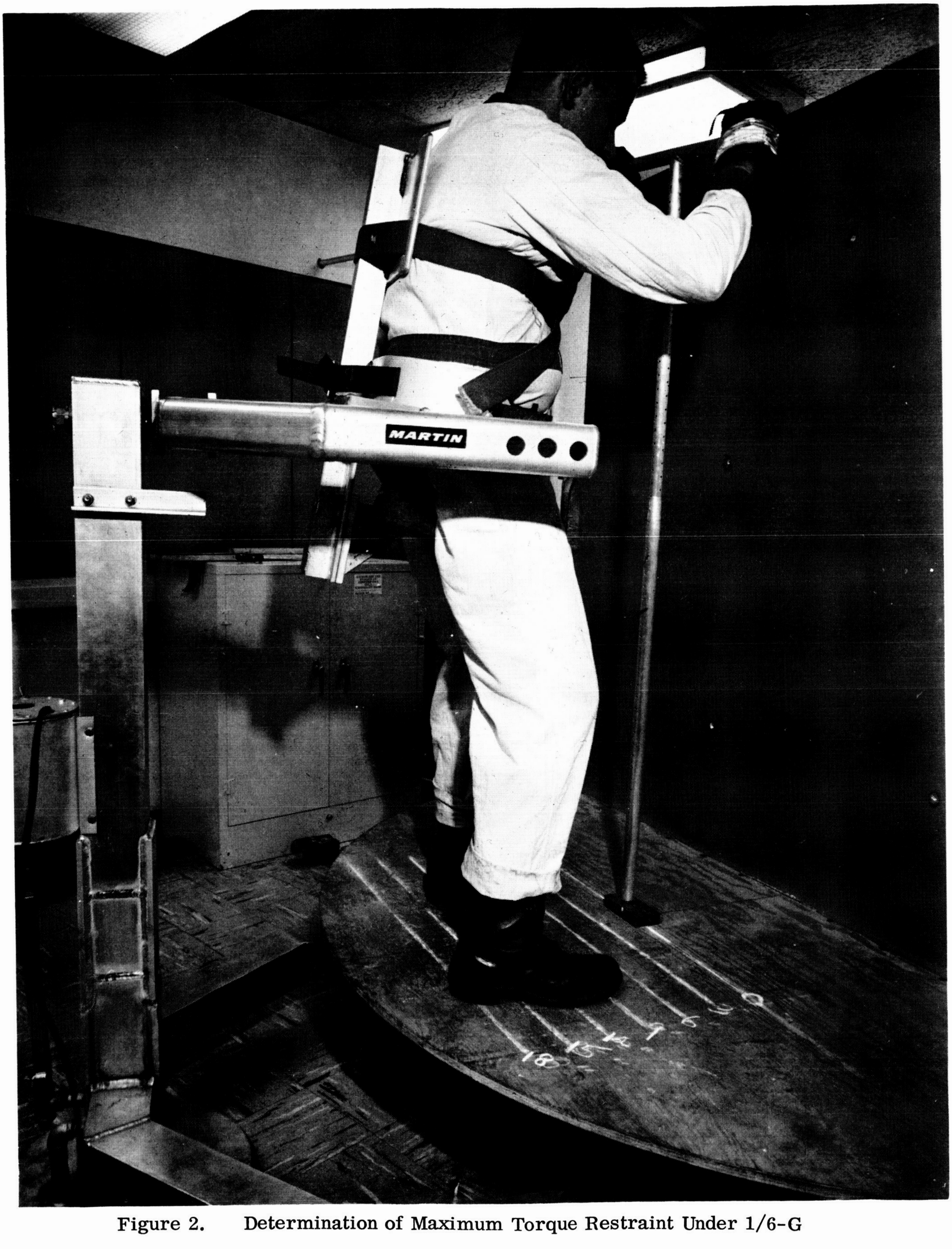

Figure 2. Determination of Maximum Torque Restraint Under 1/6-G

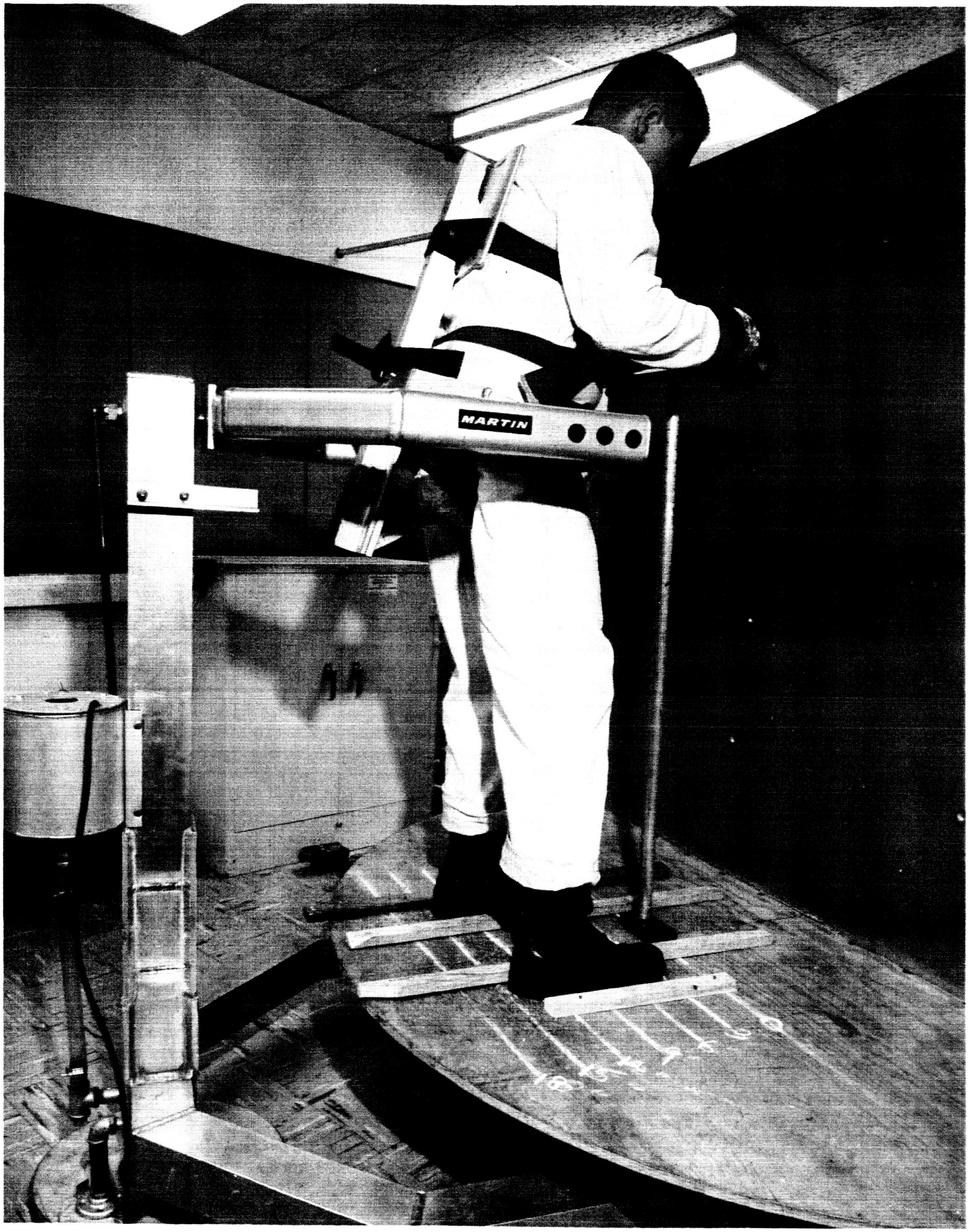

Figure 3. Determination of Maximum Torque Restraint Under 1/6-G With Feet Restrained

were obtained. Downward force measurements were not obtained with the restrained feet configuration since they would be identical to the unrestrained measurements.

After testing of the three subjects was completed, the data (see Appendix A) was averaged and statistically analyzed. The results of this analysis are listed in Table 1.

Configuration	Feet Unrestrained	Feet Restrained
T-Bar Height for Maximum Downward Force	40-50 Inches	N/A
T-Bar Height for Maximum Torque	45-50 Inches	45-50 Inches
Tool-Toe Distance for Maximum Downward Force	0-6 Inches	N/A
Tool-Toe Distance for Maximum Torque	6-9 Inches	6-9 Inches
Optimum T-Bar Height Force Range	18-22 pounds	N/A
Optimum T-Bar Height Torque Range	13-16 Ft/Lbs	45-48 Ft/Lbs

Table 1. Optimum Configurations for PLGT

Theoretically, an unrestrained astronaut should be able to exert maximum forces and torques equal to 1/6th of his body weight (excluding apparel, equipment, etc.) on the lunar surface. Greater forces can be obtained when the astronaut is restrained, or when leverage can be utilized between the surface and the work source. The study indicated that the unrestrained astronaut could utilize but 35% to 68% of his 1/6th weight capability in applying torque and force. Greater vertical forces could be exerted than torque restraint. These results are in agreement with those established during the Human Factors testing program for the NASA Powered Space Tool Project. Results of the current study also revealed that an astronaut could exert approximately three times more torque with the feet restrained than unrestrained.

During an exploration excursion of the lunar surface, the ability of the astronaut to restrain torquing forces will depend partially upon the characteristics of the surface materials. Reference 1 indicates that a static load of 1 psi will penetrate no more than ten centimeters below the lunar surface, and a dynamic load of 12 psi will penetrate no more than 30 centimeters below the surface. A 95 percentile operator, plus apparel and equipment totaling 300 pounds, would present a static load of approximately 0.33 psi, and would sink approximately 1.3 inches into the lunar surface. This may assist the astronaut in restraining the torquing forces exerted by the PLGT. It is anticipated that the astronaut's actual torque restraining ability should attain a value somewhere between the measurements for the "restrained" and "unrestrained" conditions monitored during the lunar gravity simulator tests. It may be desirable to provide cleats or other similar devices on the bottom of the boots to attain proper footholds if large force applications are required.

The study has resulted in the definition of the outer tool envelope with respect to optimum height, handle location, and general configuration. Since the astronaut may be required to lift and control the tool up to angles of 90 degrees to the vertical body axis, it is desirable to have the tool center of gravity located at or near the auxiliary handle. The auxiliary handle should be at least 5 inches long, and located at a right angle to the plane of the T-bar handle. Emperical evaluation using several subjects indicated the optimum distance between handles to be approximately 10 to 15 inches. The T-bar handles should also extend 5 inches beyond the vertical body of the PLGT.

The temporary stowage of lunar surface samples can be accomplished in one of three ways:

- A separate hand-held container can be fabricated which could be alternately carried and set down on the lunar surface by the astronaut when a two-hand task is performed.
- The specimens can be stored in pouches on a belt around the astronaut's waist or shoulder.
- The stowage compartments can be integrated into the PLGT thus relieving the astronaut of additional encumbering apparel. This, of course, will result in a bulk increase of the PLGT.

Additional Human Engineering considerations for the PLGT are as follows:

- Provide 1-inch diameter handles unless molded grips are provided to accommodate the Apollo gloves.
- Special hand grips should be evaluated, along with the operator-tool interface when the Apollo suit becomes available later in the program.
- Additional tools or gadgets should not be required to prepare the tool for operation or to change the attachments.
- Handles should fold in-line with the centerline of the tool when not in use.
- On-Off switch should be of the trigger type with Lock-On capability.
- Tool controls should be located on or near the T-bar handle.
- A built-in battery check capability should be provided.
- The deflecting shield around the chisel or drill attachment should be a transparent material so the operator can see the point of impact or drilling.
- The tool should have round surfaces wherever possible to prevent tool hang-up on clothing and foreign objects.

- Fifteen pounds or less of combined force and torque should be required on the part of the astronaut during operation.
- The tool should be provided with a non-reflective surface or finish.

Lunar Geological Factors

General. - The geology of the lunar surface will significantly influence the design requirements for the exploration hand tools. Specific geological factors, and their influence upon the tool design include:

1. Hardness or drilling toughness of lunar surface material - PLGT power pack (battery) capacity, energy of impacting mechanism, type of coring and chipping bits, and motor power.
2. Density of lunar specimens - Size of sample-carrying case required for transporting a nominal number of specimens.
3. Fragility of samples - Diameter of PLGT coring bits required to obtain consolidated speciments.
4. Local topography - Transportability of all equipment.

To evaluate the geological interface areas affecting tool design, a review of the lunar geological model which is currently accepted by most authorities (ref. Appendix B) is required. The lunar geological model and its probable effects on the tool selection and design is presented below.

Any evaluation concerning lunar surface and subsurface characteristics must take into account the origin of the materials. There is little question among authorities that both meteorite impact and volcanic activity have contributed to the origin of the materials. There are, however, some differences of opinions about the relative contribution of each process. The precise nature of the lunar surface materials is also somewhat speculative. Some of the methods used to study the lunar surface and the inferences drawn from these analyses include:

Infrared emission - low thermal conductivity
Radar reflection - low density
Polarization - agglomerated powder of opaque grains
Photometry - highly porous, complex irregular surface
Albedo and Color - nonterrestrial reflectivity
Telescopic Observation - lunar morphology
Ranger VII Photographs - details of surface, stratigraphy, ans suggestive information about lithology.

Lunar Morphology. - The most prominent features of the lunar surface are the myriads of pock marks - craters which range in size from less than 10 feet in diameter to tens of miles across. The large craters which are greater than 1200 feet in diameter are considered "primary craters" caused by impacting meteorites. Smaller craters, less than 1/16th the diameter of the primary craters, are considered to be secondary and probably originated by a "splash" mechanism through material thrown out by impacting primaries striking the lunar surface. The relatively flat floors of large craters have been called maria and are lowlands. The vast rugged regions of overlapping craters are the highlands. Probably of impact origin are the lunar rays which radiate out from younger craters such as Tycho. Some of these rays extend outward for several hundred miles. There has been much discussion concerning the thickness and composition of the lunar rays. The high reflectivity of these rays suggest a material similar to volcanic glass.

Exploration of typical small craters will undoubtedly be included during the lunar surface excursions of the LEM astronauts. Traversing the 20 to 30 degree walls of a crater may be difficult under the 1/6-G condition for the pressure suited astronaut. Therefore, the possible utilization of the PLGT as a support or stabilization "staff" for the astronaut will be considered. Perhaps two supporting "staffs" may be more efficient for stabilizing the astronaut during crater descent and ascent. The second "staff" could possibly serve the additional function of a sample and dust retriever.

Types of Materials. - On the basis of published research (ref. Appendix B), it is generally conceded that a thin layer of fragmental "debris" covers the bedrock of the moon. The debris is probably less than one foot thick, being thinnest on the maria, and thickest in pre-debris declivities. The structure of this clastic matter may be unusual (fairycastle, tinker toy, skeletal fuzz, etc.) and the grain size probably varies from dust and sand to blocks of rubble. Ranger VII photographs show apparent large rock blocks protruding from the debris. The fragmental material is considered to consist of meteorite dust and bits; and dust, sand and blocks blasted and pulverized by meteorite impact from the lunar rock crust. Volcanic ash, lapilli, and scoria fragments may be present in the unconsolidated veneer over the lunar bedrock. The possibility exists that this loose material may be welded or fused. One authority suggests that fusion would occur through the "sputtering" effects of micrometeoritic activity. The rock beneath the clastic layer varies from the maria to the highlands.

It appears that a variety of equipment types will be required to obtain samples of all possible classifications of lunar surface materials. If the surface dust is not compacted, a long handle scoop or shovel capability will be required. If the surface dust is welded or fused, the shovel may suffice but most probably the power capability of the PLGT coring or chiseling mechanism will be required. Samples of the blocks of rubble undoubtedly will require the use of the PLGT. Possible fragility of the unusual clastic structures may require careful chiseling of a small block sample by the astronaut using a spade-like tool.

Maria Materials. - The lunar surface materials located in the marial regions are probably basaltic, chiefly aa lava or blocky type, rough and irregular surface, with some pohoehoe or ropy types. Another opinion proposes the possibility of alternating ash and lava flows, while others suggest fluidized ash flows which may be rhyolitic and welded (welded tuff similar to rhyolite in properties). The concensus of opinion favors basalt.

Crater Rims. - Since most authorities feel that the craters are produced by impact, the rims should be composed of an ejecta blanket of crushed rock. Any lithologies from basaltic to acidic igneous may be present mixed with meteorite fragments. The floors of young craters are likely to be brecciated, with crevasses filled with rubble and finer debris. Slopes down into the craters should be covered with talus.

Again, it appears that the astronaut may require a scooping or shoveling capability in addition to the PLGT for obtaining specimens.

Highlands. - It is generally conceded that the continents, or highlands, consist of rock of granitic affinities or siliceous igneous types. If tektites are of lunar origin the implication is that granitic rocks may comprise the lunar crust beneath the unconsolidated debris over wide areas. The form or texture of the rock may be a gloss fine-grained or coarse grained lithology. This material can present coring problems, since it may possess a hardness number of 6 on the Mohs scale.

The presence of granite implies border facies of other compositions of local distribution including andesite-diorite, basalt-gabbro, and related clans.

Although the initial lunar landings will be in the marial rather than continental areas, the design of the PLGT should possess growth potential and be capable of coring or chipping the extremely hard lunar granites. This requirement will probably require a rotary-impact rather than a pure rotary approach to the PLGT mechanisms.

Summary of Rock Types. - Table 2 presents a summary of major rock types which should be present in the marial and continental areas.

Rock Properties	Location	
	Maria	Continents
Type	Igneous, aa type lava most common, some pahoehoe, porphyritic and vesicular.	Igneous, vesicular, pyroclastic, some crystalline rocks (igneous and metamorphic).
Composition	Basaltic.	Siliceous, acidic.
Structure	Small scale irregularity.	Very irregular, much fragmentation, scarred by numerous meteor impacts.
Lunar Dust	2 - 5 cm.	Great irregularity of this surface has concentrated dust formed on steep slopes into thicker deposits. Lighter appearance due to greater reflectivity, and presence of lighter colored rocks.

Table 2. Summary Classification of Lunar Rocks

Density of Lunar Surface Materials. -The design of the sample-carrying device will be partially influenced by the density of the materials to be collected from the lunar surface. The volume of the carrying case should be sufficient to store a relatively large number of specimens in order to minimize return trips to the LEM during the three-hour astronaut excursions.

The specific gravity of typical lunar rocks, along with thermal conductivity and compressive strength is presented in Table 3.

Material	Specific Gravity	Compressive Strength (PSI)	Thermal Conductivity (cal/sec/cm - deg)
Rhyolite	2.44 - 2.69	$17.3 - 42.5 \times 10^{-3}$	-
Granite	2.6 - 2.67	8.25 - 33.2	$4.82 - 7.42 \times 10^{-3}$
Basalt	2.75 - 2.91	6.54 - 38.9	5.55 - 6.8
Tuff	-	0.530	-
Pumice	0.6	-	0.3

Table 3. Properties of Typical Lunar Rocks

Compressive Strength of Lunar Rocks. - The anticipated drilling or chipping toughness of the lunar rocks is difficult to precisely analyze. The non-homogenity of rock material, grain interlock and rate of shear can affect the drilling toughness of the rock. Theoretical and emperical formulas have been derived for relating the shear strength of rock materials to their compressive strength, but accurate predictions of drilling rates are difficult to obtain.

Rock penetration tests performed for other programs have revealed that pure rotary coring of the high compressive strength rocks such as rhyolite, granite and basalt will be impossible for the PLGT due to excessive axial bit pressure requirements. Therefore, a rotary-percussion action will probably be required for the hard rock materials. Feasibility penetration tests will be required to evaluate the effectiveness of the PLGT mechanisms.

Geological Sampling Equipment Summary. - It is apparent that a wide range of tool capabilities will be required in order to procure the large variety of anticipated lunar surface materials. The limited dexterity and capabilities of the astronaut will require the use of a power device (PLGT) to obtain chips or core samples of the extremely hard lunar rocks such as basalt, granite and strongly welded surface dust. In areas where the dust may not be compacted, a "shovel" or "scoop" capability is required. The procurement of consolidated samples of the unusual shaped, clastic materials may also require the use of shovel-like device rather than the PLGT in order to prevent breakage. A sample-carrying device, preferably integrated with the PLGT, will be required to transport the lunar specimens from the place of procurement to the LEM spacecraft.

Environmental Factors

General. - The lunar environment will significantly influence the design of the PLGT and auxiliary geological equipment. Factors such as temperature extremes, vacuum and the 1/6th gravitational field must be considered in detail prior to the specification and design of the exploration hand tools.

Surface Temperatures. - The maximum average temperature on the surface of the moon occurs at the point where the sun is directly at the zenith which is known as the subsolar point. It has been observed that the maximum temperature occurs when the heat flux is a maximum, that is, no phase lag is apparent. The theoretical and experimental determination of this temperature are in agreement within less than $1^{o}K.$ at an average value of $374^{o}K.$ ($213.8^{o}F$). The actual temperature at a particular subsolar point may be as high as $390^{o}K.$ ($242.6^{o}F$) or as low as $330^{o}K.$ ($134.6^{o}F$). The variation of subsolar temperature is due to the fact that the solar constant (average 1.37×10^{-6} ergs/sec-cm^2) varies slightly depending on the moon's distance from the sun, and the actual albedo ranges from less than 5% to more than 40%. The lunar temperature distribution about the subsolar point of $374^{o}K.$ ($213.8^{o}F$) decreases with increasing radii from that point.

As soon as the sun sets at any point on the lunar surface, the temperature drops within a few days to its minimum value of $120^{o}K.$ ($-243.4^{o}F$). However, the initial temperature drop upon "black out" of solar radiation can occur very rapidly. One observer measured a temperature drop from $374^{o}K.$ ($213.8^{o}F$) to $200^{o}K.$ ($-99.4^{o}F$) over a period of one hour during an eclipse. The temperature continued to decline slowly, thus indicating that the moon's surface has excellent insulation properties.

The effects of the lunar temperature extremes on the design of portable hand tools are difficult to analyze. The early LEM landings are currently planned for the equatorial marial regions during the lunar day. However, the actual temperature experienced by the equipment may vary considerably, and frequently, depending on orientation with respect to the sun and lunar surface. Operation of the equipment in the shadow of crater walls will result in lower temperatures than for operation on the open lunar surface.

Reference 1 indicates that short term experiments should be designed for satisfactory operation within the range of $220^{o}K.$ ($-63.4^{o}F$) to $360^{o}K.$ ($188.6^{o}F$). Since the lunar exploration hand tools qualify as a short term experiment, the $220^{o}K.$ and $360^{o}K.$ temperature extremes will be used as design criteria for the tools. The primary design areas requiring temperature considerations include:

- PLGT Battery Pack - Normal operating temperature range of batteries is $30^{o}F.$ to $160^{o}F.$ Therefore, thermal insulation and low temperature heaters may be required.

- Leveling Devices - Liquid leveling devices should be replaced with mechanical (gravity sensing) devices.
- Lubrication of PLGT Mechanisms - Dry surface or impregnated lubricants should be utilized in lieu of greases in the sealed motor and gear box for the PLGT.

Lunar Atmosphere. - The one aspect of lunar environment which is almost universally agreed upon is the lack of an atmosphere. Recent experiments involving radio-astronomical observations of the refractions of radio waves from cosmic radiation sources indicate an upper limit of 10^{-13} mm Hg terrestrial atmospheres. Therefore, a working pressure of approximately 10^{-10}mm Hg will be assumed for this study. The primary design areas which will be affected by the low pressure environment include:

- PLGT Battery Pack - Sealed battery cells will be required to prevent evaporation of the electrolyte.
- Heat Dissipation - Radiation dissipation of the heat generated by the PLGT motor and gear mechanisms will be required.
- Sublimation and Cold Welding - Careful selection of materials will be required for the final space-qualified models of the exploration hand tools.

Subsurface Temperatures. - The properties of low thermal conductivity and thermal inertia seem to indicate that the surface temperatures do not extend very deeply into the moon's interior, and the surface should have a superficial "skin" effect. One study shows that at a depth of 30 inches the subsurface temperatures are almost constant, varying slightly from a mean temperature of approximately 235°K. (-36.4°F) regardless of lunar surface temperatures. Temperature distribution between the surface and the 30-inch depth will fluctuate throughout the duration of the lunar day-night cycle, at magnitudes which are proportional to depth. One study has revealed that temperature fluctuations at a mean depth of 3.3 centimeters vary from 225°K. (-54.4°F) to 140°K. (-207.4°F).

The lunar subsurface temperatures will not significantly affect the geological hand tools design parameters. Sample extraction and coring will be limited to a maximum depth of 4 inches. The lower subsurface temperatures may increase the cutting efficiency during PLGT coring by increasing the rate of heat dissipation by a small amount.

Handling of the hot lunar surface specimens may present a problem to the astronaut. If the astronaut is required to touch the specimens during the "bagging" operation, the spacesuit gloves must be designed to withstand the maximum temperatures predicted for the lunar surface. An alternative solution would be to pre-cool the lunar samples before final packaging and stowage in the earth return "rock box". This could probably be accomplished by temporary storage of the lunar specimens in the shadow of the spacecraft prior to final packaging for earth return.

Illumination and Albedo. - Reference 1 indicates that a mean solar luminous constant of 13.4 lumens/ cm^2 and an average lunar normal albedo of 0.073 should be accepted for this Study.

Apollo-LEM Characteristics

The design of the PLGT and auxiliary geological exploration equipment must include considerations for the restrictions imposed by the Apollo-LEM spacecraft system. Factors such as size, weight and portability will be governed by the payload limitations and storage bay dimensions.

The design specifications for the LEM vehicle include a minimum payload weight of 250 pounds. Therefore, the design of the geological tools must include a maximum of weight-saving features, consistent with operational requirements.

The interior dimensions of the LEM equipment storage bay have not been established. Preliminary information indicates that the compartment will be "pie-shaped", with an outer peripheral dimension of 54 inches. However, the initial design specifications for the geological hand tools limited the length of any tool to 30 inches. Therefore, the PLGT will be designed for disassembly into a minimum of two sections in order to be compatible with the LEM storage compartment. Stowage provisions for the smaller tools cannot be determined until final definition of the LEM storage compartment and interface requirements with other lunar surface experiment equipment are established.

The LEM hydrogen-oxygen fuel cell possesses a maximum power operating level of 2700 watts at a nominal 28 VDC. Therefore, the PLGT power pack will be designed for possible recharging from the LEM power source.

POTENTIAL DESIGN APPROACHES

Powered Lunar Geologist Tool

General. - As a result of the basic data evaluation, it is apparent that a powered tool capability will be required by the spacesuited astronaut. This requirement is predicated on the following criteria:

1) The procurement of geological samples from hard rock formations using standard hammers and picks is a difficult task in the terrestrial environment. An identical task performed safely by a spacesuited astronaut in the lunar environment using standard tools appears to be impossible. (However, additional evaluations of standard geological tools will be conducted at a later date by spacesuited subjects.)

2) The limited vision cone of a spacesuited astronaut requires that the rock chipping or coring task be performed at a considerable distance in front of his body. This can best be accomplished by the use of a powered mechanism located on the end of a "staff."

3) Control of chipping debris by use of a debris shield is somewhat simplified by use of a powered device as compared to a hand powered hammer.

4) The use of a powered device will require less physical exertion of the astronaut.

5) The larger powered device is readily adaptable for the integration of other required geological exploration equipment such as a clinometer, solar compass, and sample carrying device.

Design Criteria. - The contractual specification for the "rock sampling device" requires that a capability for coring samples four (4) inches long and five-eighths (5/8ths) to one (1) inch in diameter be incorporated. Also, the rock sampling device should possess the capabilities inherent with a standard geologist pick. Therefore, the PLGT will be designed to perform both of these functions. A battery powered electric motor will be used to provide the required mechanical power. (Coring will be performed using a rotary-percussion mechanism, and chipping of specimens from rubble blocks or rock outcrops will be performed by use of a pure percussion action.

In view of the anticipated 3-hour lunar surface exploration time for each astronaut, the PLGT will possess at least a one-hour full load operating capability before battery recharge is required. This is predicated on an intermittent duty cycle of approximately 1:3 as the astronaut moves from place to place on the lunar surface.

Battery Selection. - Nickel-cadmium, silver-cadmium, and silver-zinc batteries were considered as potential power sources for the PLGT. Each of these batteries possesses characteristics which are desirable for use with the PLGT, depending on the specific application. Table 4 lists the general characteristics for each of the three types of batteries. Nickel-cadmium batteries are capable of many charge-discharge cycles, but are relatively heavy, and possess a lower terminal voltage. The silver-cadmium batteries are somewhat lighter, but the potential recharge cycles are less. Silver-zinc batteries present the best power to weight ratio, and the terminal voltage is highest, but the potential recharge cycles are correspondingly lower than the other two types of batteries.

Characteristics	Cell Type		
	Ni-Cd.	Ag-Cd.	Ag-Zn.
Open-Circuit Potential	1.33 Volts	1.40 Volts	1.86 Volts
End of Charge Potential	1.45 to 1.60 Volts	1.60 Volts	1.95 Volts
End of Discharge Potential	1.0 Volts	0.9 Volts	1.30 Volts
Theoretical Specific Energy	96 Watt-hr/lb.	150 watt-hr/lb.	215 watt-hr/lb.
Actual Specific Energy (state-of-the-art)	8-12 watt-hr/lb.	11-24 watt-hr/lb.	20-50 watt-hr/lb.
Recharge Cycles (Typical Satellite Application) with high rate batteries)	100-10,000	10-1000	1-250

Table 4. Characteristics of Ni-Cd, Ag-Cd, and Ag-Zn Cells

The silver-zinc type battery was selected for use with the PLGT for the following reasons:

- Contains the highest power-to-weight ratio currently available for any type of battery.
- Sealed cell types are currently available which have been subjected to spatial applications in the Mercury program, and in various satellites.

- The required recharge cycles for the PLGT on the lunar surface will not exceed the design limitations of silver-zinc batteries.

The silver-zinc cell which has been selected for use in the PLGT is produced by the Electric Storage Battery Company and possesses the following characteristics:

Type:	SS-25B High Rate Discharge
Nominal Capacity:	25 Amp-Hours
Discharge Time:	1 Hour
Discharge Current:	25 Amps
Mean Voltage:	1.5 Volts
Regulation:	1.86 - 1.20 Volts
Energy Density:	37 watt-hours/lb.
	2.7 watt-hours/In^3.
Max. Discharge Current:	250 Amps.
Cycle Life (Deep Cycles):	30
Physical Characteristics:	
Weight:	1.23 lbs/cell.
Size:	3.9" x 2.2" x 1.9"

Fourteen of the SS-25B cells will be encapsulated (overall dimensions of 5" x 5" x 16.4") to form a rechargeable power pack with an output of 21 volts and power capacity of 500 watt-hours. An automatic charging control or a constant potential supply of 28 volts will be required to recharge this battery at an approximate rate of 2 amperes (constant current) or 25 amperes maximum (constant potential). These cells operate satisfactorily over a temperature range of 32°F. to 160°F. If higher temperature operation is required, special battery materials are available which will be compatible with the higher temperatures. Lower temperature operation can be controlled by use of heaters embedded in the power pack if necessary.

The encapsulated power pack is expected to weigh approximately 19 pounds. This, of course, can be reduced by a corresponding decrease in the full-load operating time requirement for the power pack. Also, Electric Storage Battery Company engineers expect that the power density of this type battery will increase to approximately 50 watt-hours per pound within the next 12 to 18 months. This could result in a 35 percent reduction in the power pack weight.

Motor Design. - The electric motor proposed for the prototype PLGT is a permanent-magnet, direct current, mechanically commutated machine. The motor will have a power operating capacity of 500 watts and primary speed of 12,000 rpm. Appropriate speed reductions will be performed as required by the use of gears.

A permanent magnet motor is proposed in lieu of a shunt or series field in order to increase power operating efficiency. The magnets are composed of two segments diametrically opposed, having an inside radius of 1.095 inches, an outer radius of 1.295 inches, and an axial length of 1.5 inches. The material used is a single-particle domain barium ferrite magnet having a residual magnetic field of 2500 gauss and a coercive force of 3800 Oersteds. They are contained in a magnetic steel shell to complete the magnetic field. The laminations to be used will be M-19 transformer grade which possess very low electrical and magnetic losses. The commutator will be constructed from zirconium copper capable of operation at extremely high temperatures. The motor insulation will be capable of 450°F. operation.

The brushes for the motor will be constructed from 605 carbon graphite supplied by the Stackpole Carbon Company. This type brush has performed satisfactorily during low vacuum testing.

Mechanism. - The percussive action required for the PLGT will be obtained by a hammering mechanism using a rise cam and drive spring arrangement. A variable pressure spring will be incorporated in order to provide impact energy control. The mechanism will be designed to drive a non-rotating, chisel-type tool and a rotating core drill. The initial gear drive train will be designed for diamond core bits. However, if percussive type bits prove to be more efficient the gear train will be adjusted for the slower rotational speeds required for the percussion carbide bits.

PLGT Envelope. - Figure 4 illustrates a scaled version of the design envelope planned for the PLGT. This envelope is based on the following criteria:

1. Optimum height, size and spacing of the control handles is based on the preliminary human factors tests performed in the lunar gravity simulator.

2. Cross sectional dimensions of the PLGT are based on the space requirements for the SS-25B silver-zinc cell power pack.

3. A 10-12 inch space between the power pack and motor was reserved for the inclusion of a chip removal gas tank if required. However, it is anticipated that chip removal can be accomplished by use of a helical spiral on the rotary core barrel. If this proves to be satisfactory the additional space within the PLGT can possibly be utilized for temporary specimen storage.

Since the overall length of the PLGT (41 inches plus tool attachment) is insufficient to serve as a "tripod" for the spacesuited astronaut, a telescoping section is planned to allow the solar compass (or camera) mount to be extended to eye level. The compass platform is attached to the telescoping section by means of a single ball and socket joint. Two clinometers are employed to facilitate rapid leveling of the compass platform.

If the LEM television camera possesses a ranging capability, a stadia scale can be painted on the PLGT to facilitate distance and angle measurements to the roving astronaut. In addition, a rock color identification chart and measurement scale can be inscribed on the telescoping section of the PLGT.

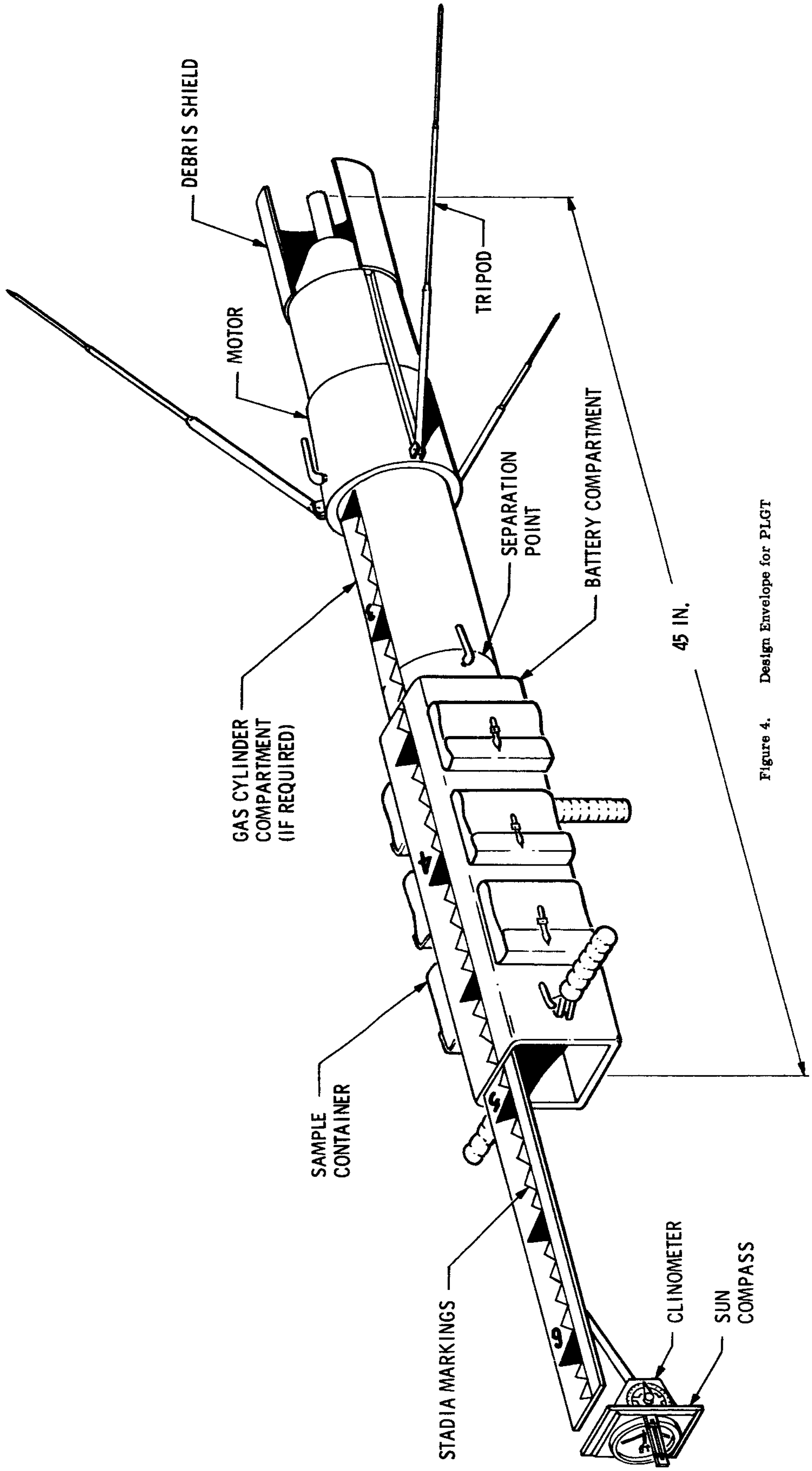

Figure 4. Design Envelope for PLGT

The PLGT illustration also demonstrates the integrated carrying pouches for temporary stowage of lunar surface specimens. The six pouches shown each have a 50 cubic inch carrying capacity (5" x 5" x 2") for a total capacity of 300 cubic inches. However, the number and size of these pouches can be increased as required. The pouches can also serve as stowage for the smaller auxiliary geological exploration devices and accessories for the PLGT.

CONCLUSIONS AND RECOMMENDATIONS

Review of current authoritative interpretations of anticipated lunar surface materials has revealed the need for a battery powered rock chipping and coring tool for procuring geological specimens from the harder materials. Design criteria for the powered tool have been established and detail design of the motor and mechanisms has commenced. The first prototype model of the PLGT will be completed during the next report period.

An Electric Storage Battery Company silver-zinc cell (SS-25B) was selected for use in the power pack for the PLGT. This cell provides the best power-to-weight ratio characteristics currently available for this particular application. The power pack will require the use of 14 of the SS-25B cells and will weigh approximately 19 pounds. Evaluation tests will be conducted on one of these type cells during the next report period.

It is recommended that the majority of other required geological exploration tools be integrated with the PLGT to eliminate the need for stowage belts or pouches attached to the astronaut. Items currently being considered for integration with the PLGT include a clinometer, solar compass, specimen carrying device, rock color chart and measuring scale. The integrated specimen carrying device can also be used to stow other geological equipment such as the magnifier lens, magnet and tool attachments for the PLGT.

The geological lunar surface task analysis will be completed during the next report period and the recommended list of auxiliary geological exploration equipment defined.

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APPENDIX A OPTIMUM T-BAR CONFIGURATION

Table A-1 represents the average of three (3) subjects' ability to apply vertical pressures on the T-bar under 1/6-G. Table A-2 represents the average of three (3) subjects' ability to apply torque, and Table A-3 represents a repeat of A-2, with the subjects' feet restrained.

Tool Distance From Toes (Inches)	T-Bar Height - Inches						Mean
	35	40	45	50	55	60	
0	16	21	22	19	20	17	19.2
3	18	20	20	20	20	15	18.8
6	18	18	19	21	19	18	18.8
9	17	18	18	19	18	19	18.2
12	16	18	18	20	18	17	17.8
15	16	18	16	18	17	15	16.7
Mean	16.8	18.8	18.8	19.5	18.7	16.8	18.2

Table A-1. Vertical Forces (Lbs) Applied to T-Bar Handle With Feet Unrestrained

Tool Distance From Toes (Inches)	T-Bar Height - Inches						Mean
	35	40	45	50	55	60	
0	16	13	14	15	15	13	14.3
3	14	13	14	13	14	13	13.5
6	15	14	16	14	15	13	14.5
9	15	12	15	16	14	15	14.5
12	11	13	15	15	14	13	13.5
15	12	15	15	16	14	14	14.3
Mean	13.8	13.4	14.8	14.8	14.3	13.5	14.2

Table A-2. Torque (Ft-Lbs) Applied to T-Bar Handle With Feet Unrestrained

Notes:
1. Tool-to-Toe Distance for Maximum Force = 0-6 inches.
2. Tool-to-Toe Distance for Maximum Torque = 6-9 inches.
3. T-Bar Height for Maximum Force = 40-50 inches.
4. T-Bar Height for Maximum Torque = 45-50 inches.
5. Operator Can Apply Approximately 68% of 1/6 Body Weight - Force.
6. Operator Can Apply Approximately 47% of 1/6 Body Weight - Torque.

Tool Distance From Toes (Inches)	T-Bar Height - Inches						Mean
	35	40	45	50	55	60	
0	36	39	43	48	39	32	39.5
3	36	41	46	43	42	34	40.4
6	38	41	45	44	45	33	41.2
9	36	40	47	48	45	36	42.0
12	37	37	41	47	43	37	40.4
15	33	33	38	41	44	35	37.4
Mean	36.2	38.5	43.4	45.4	43.0	34.5	40.3

Table A-3. Torque (Ft-Lbs) Applied to T-Bar Handle With Feet Restrained

Notes:
1. Tool-to-Toe Distance for Maximum Torque = 6-9 inches.
2. T-Bar Height for Maximum Torque = 45-50 inches
3. Operator Can Apply Approximately Three (3) Times More Torque Restrained Than Unrestrained.

Appendix B - Current Lunar Geological Interpretations

The current geological interpretations of lunar surface materials is presented below.

Dust and Rubble. - Salisbury (1960) indicates that the uppermost layer of the lunar surface is welded rubble covered by a few inches to a few feet of dust, with the dust composed of ash with fragments of iron and stony meteorites. Salisbury (Lunar Surface Layer) also states that the rubble in intercrater areas averages about 2 feet in thickness, and is thin in the maria.

Shoemaker (November 1964) states that the surface rock of the moon consists of a layer of debris, averaging less than 1 foot in thickness.

The N. A. S. International Geophysics Bulletin No. 8 (October 1964) on the interpretation of Ranger VII photographs states that large rock masses protrude from 90 meter craters. (These are depicted in a drawing in Shoemaker's report referenced above). Kuiper is quoted as stating that the maria are covered by less than 1 foot of porous material.

Gibson (1961) from observations of the March 13, 1960 eclipse suggests that the lunar surface layer is stratified with 2 or 3 layers; the top layer consists of 0.5 centimeters of sand in vacuo, the intermediate layer is several centimeters thick and characterized by a high electrical conductivity, while the lowermost layer is composed of bedrock.

A recent Russian press release states that radio frequency studies during eclipses show that the upper four inches of the lunar surface is porous material of 50 to 100% greater electrical conductivity than the underlying bedrock, and differs from it in chemical composition and mineral content.

Unusual Structure of Upper Surface Layer. - Warren (1963) gives an account of his interpretation of the unusual structure of the topmost layer depicting a skeletal fuzz, tinker toy structure consisting of opaque units spaced by thin rods, or perhaps branching linear units. This layer possesses a relatively low heat capacity.

Salisbury (Lunar Surface Layer) states that laboratory experiments reveal that the naturally occurring substance with reflectivity most closely approximating the photometric curve is the spongy lichen cladonia rangiferina, indicating that the moon is covered by a highly porous substance with very complex surfaces.

Hapke (1963) feels that the surface is covered with a fine layer of rock dust composed of particles with average diameter of 10 microns, and the layer is 90% voids by volume. Lunar polarization by reflection of sunlight is low compared to terrestrial materials. A small amount of polarization is characteristic of transparent materials of sizes approximating the wavelength of light. The lower surface is an optically thick layer of very rough material.

Basalt. - Although many references are made to lava, particularly in connection with the maria, references to specific lithologies are not as frequent as would be expected. The association of basalt and the moon's surface seems implicit. Yet, although the rock terms lava and ash flow frequently appear in lunar surface descriptions, basalt is infrequently used in describing rocks attributed to volcanism. Some specific references to the basic composition of volcanics as basalt include:

Shoemaker (November 1964), in reference to fragments of the moon surface knocked loose by impact hard enough to escape the lunar gravity, indicates that these are made of lava-like basalt or siliceous glass.

Kelley (November 1964) states that the surface of lunar lowlands are probably underlain by lava - the surface may vary from smooth to slaggy and rough, and probably consists of basalt flows with a thin cover of loose material.

Brereton (1961) refers to the basaltic maria, with siliceious continents.

Acidic Lavas or Ash Flows, Granites, and Siliceious Rocks. - A recent observation on rocks of this composition is made by O'Keefe (October 1964) in his interpretation of Ranger VII photographs. O'Keefe states that the lunar surface has been subjected to recent intermediate or acid volcanism, and cites as evidence steepsided aretes inconsistent with a typical basalt flow.

O'Keefe and Cameron (1962) speculate that if tektites come from the moon, a considerable portion of the lunar outer crust is of granitic constitution. This theory is further substantiated with the landform evidence of domes (laccoliths) associated with granitic intrusion. These authors further suggest that maria may be ash flows which are welded to permit the development of domes observed in the maria. Similarly, Salisbury (Lunar Surface Layer) proposed the possibility of maria covered by series of ash flows, possibly mixed with lava flows.

Cameron (1964) ascribes sinuous rills on the lunar surface to erosion by nuees ardentes. These are usually associated with intermediate (andesitic) and acidic (rhyolitic) volcanic activity.

To complete the array of lunar lithologies by the inclusion of sedimentary rocks, Gilvarry (1960) has proposed that the moon may have formerly contained an atomosphere derived from gases escaping from its interior. Gilvarry postulates that the maria were perhaps correctly named, and may be floored with sedimentary rocks. Although this hypothesis is not widely accepted, it is interesting to note that many researchers agree that the moon was once only 1/10 its present distance from the earth, but still discount the possibility of a vanished atmosphere and sedimentary rocks.

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